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An economic framework for the development of a resilience index for business recovery

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ABSTRACT

Several attempts have recently been made to identify the key indicators of community resilience and to group them into an overall resilience index. These studies support the evaluation of the effectiveness of resilience during recovery, and they also help establish a yardstick by which to monitor progress in resilience enhancement over time. We examine existing resilience indices in relation to economic principles and evaluate their potential to gauge and improve post-disaster economic recovery, with a focus on businesses. We conclude that the majority of indicators in use to date are not necessarily pertinent to measuring resilience at the micro-, meso- and macro-economic levels in the aftermath of a disaster. Contending that business behavior is the key to short-term recovery, we propose a framework for choosing appropriate short-run indicators toward the goal of developing an effective economic resilience index.

1. Introduction

Research on resilience to natural and man-made disasters has long focused on defining the concept and on case studies. More recently, interest has shifted to identifying individual resilience indicators or composites of them in the form of an overall index. These studies are potentially useful for assessing what factors make an entity resilient, evaluating the strength of this resilience, and monitoring progress on its enhancement. Several well-intentioned examples include Norris et al., Kajitani and Tatano, and Cutter et al. [1–3].

The main purpose of this paper is to evaluate and advance the state of the art of resilience index formulation. One major conclusion is that many of the components of resilience indices to date are not in fact important to the resilience of individual businesses or the economy as a whole during the early stages of the recovery process. We suggest this has arisen mainly because: too many of these indicators are borrowed from vulnerability studies, there has been an absence of conceptual frameworks for the formulations, there has been a lack of focus on businesses, evidence on what actually has affected resilience has been overlooked, and there is a bias toward indicators that can easily be computed with publicly available data. We propose a framework, based on economic theory and on empirical and simulation studies that measure resilience effectiveness, for the future choice of economic resilience indicators and the compilation of a short-run resilience index.

We begin the paper with a discussion of economic resilience and then outline a conceptual framework for the specification of individual resilience indicators. We then summarize some case studies and simulation analyses of economic resilience. Next we provide a critique of resilience indicators to date in relation to economic principles

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and findings. We conclude with some guidelines for the formulation of a short-run economic resilience index.

2. Economic resilience

2.1. Basic definitions

We focus on a subset of resilience pertaining to the economy. It is applicable at three levels:

- Microeconomic (individual business or household)
- Mesoeconomic (individual industry or market)
- Macroeconomic (combination of all economic entities)

The latter level overlaps with the popular focus on "community resilience" (see, e.g., [1,4]) and represents a more holistic picture. However, economists have long appreciated the importance of microeconomic foundations of macroeconomic analysis for several reasons. First, the macroeconomy is composed of individual building blocks of producer and consumer behavior as underpinnings for macroeconomic considerations stemming from group interactions. Second, behavioral considerations are best addressed first at the most elemental level. These same points hold true for community resilience.

We offer the following definitions of economic resilience based on Rose [5,6]:

Static economic resilience: The ability of a system to maintain function when shocked. This is the heart of the economic problem, where ordinary scarcity is made even more severe than usual, and it is imperative to use the remaining resources as efficiently as possible at any given point in time during the course of recovery.

Dynamic economic resilience: Hastening the speed of recovery from a shock. This refers to the efficient utilization of resources for repair and reconstruction. Static resilience pertains to making the best of the existing capital stock (productive capacity), while this aspect focuses on enhancing capacity. As such, it is about dynamics, in that it is time-related. Investment decisions involve diverting resources from consumption today in order to reap future gains from enhanced productivity.

An important distinction between economic resilience and the perspective often found in engineering approaches is the focus of the former on the flows of goods and services (typically measured in terms of gross domestic product or employment), rather than the stock of assets (typically measured in terms of property damage). Flows are direct measures of economic well-being (e.g., GDP, employment). At the same time, they are more challenging. Property damage takes place at a given point in time but the loss of the flow of goods and services, often referred to as "business interruption", just begins at this point and continues until the economy has recovered, or reaches a "new normal". Therefore, they are complicated by individual behavioral considerations and public policy decisions. Kajitani and Tatano [2]; p. 757 have stated that "Resilience options are regarded as measures that help reduce the business interruption after the physical damage occurs to structures".

Referring to the ability, or effectiveness, of a resilience tactic implies a level of loss reduction will be achieved. Hence, the definition is contextual—the functional level has to be compared to the level that would have existed had the tactic not been implemented. This means a reference point or type of worst case outcome must be established first. Further discussion of this oft-neglected point is provided below.

Another important distinction is between *inherent* and *adaptive* resilience. The former refers to aspects of resilience already built into the system, such as the availability of inventories, excess capacity, input substitution, contractual arrangements accessing suppliers of goods from outside the affected area (imports), and the workings of the market system in allocating resources to their highest value use on the basis of price signals. Adaptive resilience arises out of ingenuity under stress, such as Draconian conservation otherwise not thought possible (e.g., working many weeks without heat or air conditioning), changes in the way goods and services are produced, and new contracting arrangements that match customers who have lost their suppliers with suppliers who have lost their customers.

We provide an admittedly crude but operational metric of resilience. *Direct Static Economic Resilience* (*DSER*) refers to the level of the individual firm or industry (micro and meso levels) and corresponds to what economists refer to as "partial equilibrium" analysis, or the operation of a business or household entity itself. *Total Static Economic Resilience* (*TSER*) refers to the economy as a whole (macro level) and would ideally correspond to what is referred to as "general equilibrium" analysis, which includes all of the price and quantity interactions in the economy [5]. The market itself, when functioning properly, is a major source of resilience at the meso and macro levels because it provides signals of increased resource scarcity that indicate where reallocations should best be made by individual producers and consumers [7].

An operational measure of *DSER* is the extent to which the estimated direct output reduction deviates from the likely maximum potential reduction given an external shock, such as the curtailment of some or all of a critical input. In essence *DSER* is the percentage avoidance of the maximum economic disruption that a particular shock could bring about. A major measurement issue is what should be used as the maximum potential disruption. For ordinary disasters, a good starting point is a linear, or proportional, relationship between an input supply shortage and the direct disruption to the firm or industry. Note that while a linear reference point may appear to be arbitrary or a default choice, it does have an underlying rationale. A linear relationship connotes rigidity, the opposite of the "flexibility" connotation of static resilience defined in this paper. Analogously, the measure of *TSER* is the difference between a linear set of indirect effects, which implicitly omits resilience, and a non-linear outcome, which incorporates the possibility of resilience.

Also, while the entire time-path of resilience is key to the concept for many analysts, it is important to remember that this time-path is composed of a sequence of individual steps. Even if "dynamics" are the focal point, it is important to understand the underlying process at each stage, i.e., why an activity level is achieved and why that level differs from one time period to another. As presented here, static resilience helps explain the first aspect, and changes in static resilience, along with repair and reconstruction of the capital stock, help explain the second.

We illustrate the application of the definition with the following case study by Rose et al. [8], who estimated the national and regional economic impact of the September 11, 2001, terrorist attack on the World Trade Center. The researchers refined some available data indicating that more than 95 percent of the businesses and government offices operating in the WTC area survived by relocating; the vast majority to Mid-town Manhattan or across the river in Northern New Jersey. Had all of these firms gone out of business, the potential direct economic loss in terms of GDP would have been $43 billion. However, relocation was not immediate, taking anywhere from a few days to as long as eight months for the vast majority of firms. Rose et al. [8] calculated this loss in GDP at $11 billion. They were then able to apply the resilience definition provided in this Section to estimate that the effectiveness of relocation as a resilience tactic in the aftermath of the 9/11 attacks was 72 percent ($43 minus $11, divided by $43). This study highlights the importance of excess capacity as a resilience tactic. This more intensive use of resources is also the theme of the recovery in the current great recession in the U.S. and other countries, as employment recovery significantly lacks the recovery of output. The experience of New York thus signals a significant change in approaches to disaster recovery, which typically emphasized prompt rebuilding. Coupled with stronger requirements for mitigation, and hopefully some general accumulated wisdom, we are recovering less by reflex action and more by intelligent planning (see also [9,10]).

2.2. *Measurement of economic resilience*

Several studies have examined economic resilience empirically or with the use of simulation studies. The major pioneer is Tierney, who surveyed businesses in the aftermath of the Northridge Earthquake [13] and Midwest Floods [14]. Rose and Lim [15] translated Tierney's findings into specific micro-level measures of resilience of the Los Angeles electricity system. They identified such factors as time-of-day-use, electricity “importance”, and production recapture as key to understanding why businesses that averaged an X% reduction of electricity were able to continue operation with much less than an X% reduction in their production goods and services. In fact, they found that these micro-level tactics resulted in a reduction of business interruption losses by 90%, an amount consistent with Tierney's survey responses.

Rose and Liao [12] also used the Tierney survey responses relating to water service disruptions to evaluate two major types of resilience: conservation of scarce inputs and enhanced ability to substitute other inputs for water. They integrated these findings into a method that enabled them to alter the key parameters in the production functions of a computable general equilibrium (CGE) model to ascertain sectoral and economy-wide effects of a potential devastating earthquake in Portland, Oregon. However, these two resilience tactics are limited and resulted in reducing losses by only a few percent. Macro impacts follow from micro impacts of resilience through general equilibrium effects (basically price and quantity multiplier effects). These are more sophisticated than in the standard input–output (I–O) model, which is based on linear relationships that omit the workings of markets and are unidirectional (typically entirely negative for basic losses in the case of a disaster, and entirely positive for resilience). The CGE model is able to capture the moderating influence of lower prices from reduced demand, as well as the upward pressure on prices due to decreased supply, where in this case the demand side was the dominant one. The net effect, however, yields implicit macro multipliers lower than the standard I–O multipliers, in this case averaging about 1.9. This means that the micro impacts of resilience are slightly greater than the macro impacts (general equilibrium effects alone are equal to $1.9-1.0$, the latter being the direct effect base).

Other approaches to estimating resilience have been less evidence-based, but are still prominent in the literature. Several resilience factors have been incorporated into FEMA's loss estimation tool—HAZUS (see, e.g., [16,17]). In the Direct Economic Loss Module (DELM) they included factors for individual businesses making up lost production at a later date by working overtime or extra shifts after their utility lifelines had been restored or after building damage had been repaired. These “recapture factors” were based loosely on a synthesis of the literature, and the indication is that these factors are very high (ranging between 50% and 98% for most sectors) for short periods. That is, customers are unlikely to cancel their orders for the output of disaster-sickened industries for short periods of time, because they have inventories on hand or long-standing supply-chain relationships. On the other hand, this type of resilience is likely to decline over time, and is likely to fall to zero after one year, if not after several months.

The HAZUS Indirect Loss Module (IELM), includes such resilience factors as inventories, excess capacity, and the substitutability of increased imports and exports. However, there are no definitive estimates of the effectiveness of these resilience tactics for all contexts, so it is necessary for the user to access primary or secondary data to specify this.

Kajitani and Tatano [2] used a survey to estimate the resilience of Japanese industries (meso level) to various types of lifeline disruptions from disasters. They found, for example, that, for industrial sectors, resilience to lifeline service disruptions was less than 10% for electricity, 38% to 71% for water, and 63% to 96% for natural gas. Their findings represent the most definitive to date on a broad spectrum of resilience tactics.

Several simulation studies have been undertaken to estimate the effects of resilience on losses from disasters [18–21]. For example, Rose and Wei [20,21] used public sources of data to evaluate the resilience potential of such tactics as excess capacity, inventories, and export diversion to reduce potential losses from a shutdown of the Port Arthur/Beaumont complex. The authors found that the reduction in regional GDP could be cut by more than 70% with the implementation of resilience tactics, including ship diversion, stockpiles, excess capacity, and inventories.

3. A conceptual framework for economic resilience

We present a conceptual framework for an analysis of economic resilience based on economic production theory, an abstract approach to how businesses combine various inputs to produce outputs to sell to consumers. The framework is readily extended to how businesses interact in supply chains, and in one approach, known as computable general equilibrium (CGE) analysis, the economy is viewed as a set of integrated supply chains. The operation of businesses is still the focus of this approach, but their role in backward and forward linkages with other businesses can be examined in the context of the entire economy. Interestingly no resilience index in any discipline of the social sciences today has provided a conceptual framework. We note that these approaches emanate from mainstream (neoclassical) economics, which is not without its limitations. It is often criticized for relying too much on optimizing behavior and equilibrium concepts. Below, we note how it can be adapted to overcome some of these limitations.

Business resilience has two sides. Customer-side resilience copes with the disruption (quantity and timing) of the delivery of inputs, and pertains to ways to use resources available as effectively as possible by both businesses and households, i.e., it is primarily associated with static resilience. For example, at a given point in time, meaning with a given fixed capital stock, in the context of electricity, or any critical input, supply disruption, resilience is mainly a demand-side issue. In contrast, supply-side resilience is concerned with delivering outputs to customers, and could include the establishment of system redundancy (a form of static resilience), but usually requires the repair or construction of critical inputs (i.e. dynamic resilience). Repair of the capital stock, or supply-side efforts, are the domain of the input provider and are a completely separate matter from customer-side resilience.

Government has both demand-side and supply-side resilience features in a manner similar to business. Of course, government at various levels plays a key role in economic recovery, so this is an added dimension of resilience in this sphere. Improvements in the quality and quantity of emergency services can be thought of as resilience enhancement. Increases in financial or in-kind disaster assistance and the effectiveness of their distribution to the affected parties promote recovery as well. However, the provision of aid can have disincentive effects on resilience, just as it does for mitigation when those who suffer from a disaster because they have not undertaken mitigation are "bailed out."

In addition to customer-side resilience, households have supply-side resilience considerations with respect to providing their own services (e.g., cooking to prepare meals) or providing labor. However, household activities are not counted in national income accounts and are difficult to value, so supply-side resilience is less meaningful for households.

Resilience options for business are summarized in Tables 1 and 2 following Rose [11]. Each table lists a major category of resilience and provides examples. Each specifies a prior action that can be taken to enhance each type of resilience. Each table also specifies the extent to which the resilience category is inherent and adaptive. In addition, the applicability of the type of resilience to factors of production is specified in terms of the letters capital (K), labor (L), infrastructure (I), materials (M), as well as for the output (Q) that they produce. Finally, obstacles to the implementation of each type of resilience are listed. Capital letters associated with each of these inputs or outputs represent a strong relationship, while lower-case letters represent a weak one. The same convention is used to denote the strength of inherent or adaptive resilience which is denoted by the letter X. For example, a firm can readily import all inputs except infrastructure services and physical capital, which are more limited because of their stationarity. Factories cannot readily be relocated but equipment can be; thus these variables are relevant to relocation resilience, but are limited and hence connoted by lower case letters. Another example is that inherent conservation is primarily already accounted for by maximizing behavior, but we include it as at least weak, because not all firms actually maximize their production relationships.

Table 1 presents resilience strategies for businesses on the customer side. The first category is Conservation and examples include automated controls to monitor the flow of inputs (e.g., water) to help make sure they are used only in times when they are needed and the reduction of non-essential uses. Prior action can be taken to promote resilience by closing systems to promote recycling, such as in the re-use of circulating water. Conservation is only minimally inherent because economists typically assume that most inherent conservation options are currently being maximized. Thus, most conservation options pertain to adaptive applications. All inputs—capital, labor, infrastructure services, and materials—can be conserved. The major obstacle is necessity of the input into the production process. Similar explanations are provided for other resilience options for the case of business customers.

Analogously, Table 2 presents resilience options on the business supplier side. This includes a different set of resilience categories in several cases. For example, delivery logistics refers to the fact that suppliers must deliver their products to customers. Examples include shoring up the network of wholesale and retail trade, contingency contracts with transportation companies, and planning exercises. The rubric for prior action is "broadening the supply chain". These actions are strong at both the inherent and adaptive levels. As with most cases of supply-side resilience, they are applicable primarily to output. The major obstacle in implementing supplier-side resilience is the condition of the transportation network.

The inputs into economic activity noted in Table 1 serve as the independent variables for a formal production function in which the influence of several types of resilience can be linked directly to them or to the production function parameters. For example, Rose and Liao [12] have shown how conservation is linked to the productivity term, and how input and import substitution are linked

Table 1
Resilience options: business (customer-side).

Category	Prior action	Inherent	Adaptive	Applicability	Obstacles
Conservation • automated controls • reduce non-essential	Close system to promote recycling	x	X	K, L, I, M	Necessity
Input substitution • back-up generators • cross-training	Enhance flexibility of system	X	X	K, L, I, M	Specialization
Import substitution • mutual aid agreements • re-routing of goods	Broaden supply chain	X	X	k, L, i, M	Transportation
Inventories (Stockpiles) • fuel supplies • labor pool	Enhance; protect	X	x	k, L, i, M	Storage capacity
Excess capacity • system redundancy • factor-in risk	Build and maintain	X	x	K	Dilapidation
Input unimportance • decrease dependence • segment production	Reduce dependence on critical inputs	X	X	K, l, I, M	Integrated process
Relocation • back-up data centers • physical move	Arrange for facilities in advance	x	X	K, L, I, M	Coordination
Production recapture • information clearinghouse • restarting procedures	Arrange long-term agreements	X	X	Q	Capacity
Technological change • change processes • alter product characteristics	Increase flexibility	x	X	K, L, I, M, Q	Lack of ingenuity
Management • emergency procedures • succession/continuity	Train; increase versatility	X	X	k, L, m	Pressure

to the elasticities of substitution of a constant elasticity of substitution (CES) production function.

The production theory framework presented above reflects mainstream economics, but has its limitations (e.g., assuming maximizing behavior and a limited number of explanatory factors). It is intended as a starting point and can be enhanced by incorporating features of the behavioral theory of the firm (e.g., non-optimizing behavior and more managerial considerations) and bounded rationality in general (considerations of limited time horizons, limited information and limited ability to process it). One way to do this is to add a managerial term to the production function.

4. Assessment of resilience indicators and indices

Below we assess several recent efforts to compile a resilience index (RI). We focus on short-term aspects of resilience, as we submit that at least in the short run (e.g. in the first year after a disaster) business behavior is most crucial to economic recovery. A summary of the reviewed indices is presented in Table 3, in which we include the approach chosen by the various authors, the conceptual basis of the index, and some sample indicators. The last column highlights problems we identified with the proposed resilience indices. The attribute "incomplete" indicates that an index comprises some useful elements to describe the short-run resilience of businesses but needs to be supplemented with additional elements for a more complete representation. On the other hand, the attribute "irrelevant" denotes indices containing elements that are unsuitable for this purpose.

It appears that many of the shortcomings of the discussed indices arise from the fact that the component indicators relate to general economic characteristics rather than facets specific to the operation of businesses in the aftermath of disasters. Many of these indicators are contained in vulnerability indices, and the implicit assumption seems to be that resilience is just the flip side of vulnerability, and without much rationale for drawing this conclusion.

Table 2
Resilience options: business (supplier-side).

Category	Prior action	Inherent	Adaptive	Applicability	Obstacles
Delivery logistics • shore-up network of wholesale/retail trade • contingency contracts w/transport companies	Broaden supply chain	X	X	Q	Transportation
Export substitution • expand markets • re-routing	Enhance flexibility	X	X	Q	Transportation
Inventories (Stockpiles) • strengthen storage facilities • pooling of resources	Enhance; protect	X	x	Q	Storage capacity
Excess capacity • system redundancy • factor-in risk	Build and maintain	X	X	K	Dilapidation
Relocation • move closer to customers • field operations	Arrange for facilities in advance	x	X	K, L, I, M	Coordination
Production recapture • in relation to customer needs • practice restarting	Arrange long-term agreements	X	X	Q	Capacity
Technological change • change processes • alter product characteristics	Increase flexibility	x	X	K, L, I, M, Q	Ingenuity
Management • project demand change • prioritize goods & services	Increase versatility	X	X	Q	pressure
Reduce operating impediments • assist family workers • streamline paperwork	Recovery planning	x	X	K, L, I, M	Cognition

For example, the RI derived by Cutter et al. [3] includes housing capital, equitable incomes, employment, business size, and position access. Sub-component variables include percent employment, percent home ownership, business size, female labor force participation, and a proxy for single sector employment dependence. First, hardly any of these indicators match those derived in Section 3 above from a solid economic conceptual framework. Also, few have much to do with the operation of an individual firm or the economy as a whole. Percent employment is a good initial measure of excess capacity in the labor force from which to draw; however, it does not take into account the fact that disasters are able to draw additional labor from neighboring communities either through market signals (higher wages) or for altruistic motivations. Female labor force participation is not a good proxy for labor supply because disaster situations can readily inspire dramatic changes in this variable (e.g., the major increase in female labor force participation during World War II). Single sector employment dependence is, however, an excellent indicator of resilience at the macro level because, as the authors note, a diversified economy is much more resilient. The remaining indicators are much more tenuous. For example, business size and income equality are indicators that cannot be enhanced in the short-run, or even medium-run, aftermath of a disaster. They have little bearing on the operation of individual businesses. It is not even evident that they can affect resilience in the long run. For example, it is likely that larger firms are more resilient than smaller ones (but see also [22], for the opposite finding). However, does this mean a community should favor large firms? Moreover, there are some reasons why large firms may not contribute as much to community resilience, given their absentee ownership and thus their likely relatively lower commitment to the locale. The income inequality variable is very pertinent to how households fare in the aftermath of a disaster—a very important consideration, but not necessarily one that has a great effect on businesses. Aside from the important separate issue of equity, lower income groups do not have savings on which to draw to maintain a reasonable living standard, which, in standard economic terms, means lower demand for goods and services, and hence lower levels of economic activity. However, often this situation is compensated by government and private philanthropic assistance.

Table 3
Assessment of economic and community resilience indices.

Study	Approach	Conceptual/Empirical Support	Sample indicators	Problems
Cutter et al. [3]	Adapted vulnerability index	Success of vulnerability index several case studies	Percent employed Business size income Equality	Incomplete Some irrelevance
Bruneau et al. [23]	4 Rs framework	Systems engineering	Avoidance of losses Redundant capacity Stabilizing measures Recovery time	Incomplete Includes mitigation
Jordan et al. [24]	Content analysis	Prevalence of (sub)indicators	Employment Home ownership Income equity Single-sector dependence	Incomplete Some irrelevance
Mayunga et al. [25]	Capital-based strategies	Extension of social-capital approach	Household income Property value Employment investments	Incomplete
Fisher et al. [26]	3 Rs framework	Expert judgment	Excess capacity Inventories Input/import substitution	Partly complete Single case study
Norris et al. [1]	Literature review	Social psychology	Diversity of economic resources Equity of resource Distribution	incomplete Process-oriented
Burton [28]	Based on vulnerability	Hurricane Katrina recovery	Percent employed Household income Business size	Incomplete Some irrelevance
Rose [11]	Production theory macroeconomics	Several case studies	Inventories Excess capacity Input substitution Business relocation	Narrowly economic

The number of physicians per ten thousand population is a rough proxy, and is somewhat connected to labor productivity, but again outside aid is likely to help overcome a serious deficit of this indicator.

At best some of these indicators are applicable to long-term recovery, usually a period of several years, but are not relevant during the short-term, say, first year. Thus, they are only applicable to major disasters. One defense of the choice of several of these variables is that they can be used to gauge some improvements in a disaster resilience index over time. Still, improvement on some variables, such as business size, might not be without negative side effects, which are rarely if ever mentioned. They are also useful in assessing the self-reliance of a community, which is an important consideration. However, the bottom line is that this set of indicators has many serious omissions.

Bruneau et al. [23] outline a conceptual framework for the quantitative assessment and improvement of the seismic resilience of communities anchored in an engineering-based definition of resilience. Focusing on critical infrastructures they define the resilience of both physical and social systems as consisting of the high-level properties robustness, redundancy, resourcefulness and rapidity ("the 4 Rs"), and apply the concept at the technical, organizational, social and economic level. In addition, they stipulate that key to their framework are reduced failure probabilities, reduced consequences from failures and reduced time to recovery. Resourcefulness is a measure of ingenuity under stress that corresponds to adaptive resilience. Rapidity is consistent with our definition of dynamic economic resilience. Redundancy is equated with resource diversity (excess capacity). Robustness corresponds to the effectiveness of mitigation in reducing the initial shock. Bruneau et al. also provide some illustrative economic performance measures: avoidance of direct and indirect economic losses (robustness); untapped or excess economic capacity, e.g. inventories, suppliers (redundancy); stabilizing measures, e.g. capacity enhancement and demand modification, external assistance (resourcefulness); and optimizing time to return to pre-event functional levels (rapidity). Some of these proxies match a number of business resilience options presented in Tables 1 and 2 and address the microeconomic level. The main criticism of this study is the rather broad definition of resilience that includes the reduction of failure probabilities and hence of potential losses through mitigation actions prior to an incident. We understand resilience rather as reducing the consequences of failure and assuring business/service continuity under adverse conditions. Nonetheless, the framework of Bruneau et al. [23] is one of only a few studies that goes beyond a simple definition and superficial discussion of resilience.

In support of community disaster recovery and to understand the requirements for achieving a higher level of community resilience, Jordan et al. [24] carried out a content analysis of the scientific disaster literature to extract a set of indicators to measure resilience. According to their study, which tried to capture relevant indicators across the social sciences, engineering and practitioner-oriented fields, economic resilience can be characterized by employment, home ownership, income equity, and single-sector dependence. These indicators overlap with some of those used in the RI derived by [3] and consequently suffer from the same shortcomings. The exception is single-sector dependence, which is a good measure for how diversified and hence resilient the overall economy is (see also the macroeconomic level resilience discussed in [11]). Employment or income equality would not have a major bearing on the economic resilience of individual businesses or the economy as a whole in the short-run for the reasons discussed before.

Mayunga [25] chose a capital-based approach to address community disaster resilience and included five major forms of capital in his analytical framework to develop a community disaster resilience index: social, economic, physical, human and natural. He defines economic capital as the financial resources that people use to achieve their livelihoods and hence proposes household income, property value, employment and investments as economic resilience indicator components. Along the same lines he defines physical capital as referring to the built environment and includes, among others, the number and location of businesses/industry as a resilience measure. Mayunga's choice for the proposed subset of economic resilience indicators is in some cases directly linked with vulnerability reduction prior to a disaster event, e.g., income that provides for insurance or access to loans to increase the level of household preparedness or take protective measures, such as retrofitting etc.; investment that increases wellbeing and reduces poverty. These measures would, however, be excluded from our definition of economic resilience as they are more pertinent to mitigation. Also, while certain structural and business conditions would be required to qualify for insurance, it would primarily be a mechanism that transfers risk rather than reducing it. On the other hand, the availability of income and property value (savings) could speed up the community's recovery process and stimulate economic activity. It would, however, not be expected to have a significant effect on business recovery. The number of businesses would be an appropriate sub-indicator for economic resilience if interpreted as diversification of processes and products, leading to the rapid substitutability of services and goods or to cushioning the shock to the macroeconomy.

Similar to Bruneau et al. [23], Fisher et al. [26] constructed an index for critical infrastructure resilience. Its purpose is to supplement protective-measure and vulnerability indices to aid infrastructure operators throughout the risk management process in ensuring operational continuity. With the RI being a relative measure it allows the comparison of resilience levels and the prioritization of investments to increase infrastructure resilience. The high-level components of the proposed resilience index are robustness, resourcefulness and recovery as defined by the National Infrastructure Advisory Council [27]. These major components consist of indicator subsets of various levels, which broadly correspond to some of the options in Tables 1 and 2. Robustness, for instance, includes system redundancies to compensate for dependencies between critical infrastructures, as well as the enhancement and protection of critical-product inventories. Resourcefulness consists of both pre- and post-incident sub-indicators to account for anticipation and adaptation. Proposed sub-indicators include stockpiles and alternative/new resources (excess capacity for electric power generation, import substitution for critical products and mutual aid agreements to broaden the supply chain), and training exercises in emergency procedures and business continuity. The recovery component focuses on internal and external coordination aspects but also on the duration of business interruption and the time to restart full operations as resilience performance measures. In contrast to the other RIs reviewed in this section that focus on community resilience, Fisher et al. [26] narrow their study to critical infrastructures as risk receptors whose management is aimed at maintaining acceptable levels of operation under stress and speeding up recovery. This approach is consistent with the way companies address business risks to increase their resilience to crises and consequently avoid or reduce downtime.

Norris [1] proposes a theory of community resilience by defining it as a process that links resources that are robust, redundant or rapidly accessible (so-called adaptive capacities) to post-disaster adaptation. In this context, resilience is not equated with an outcome but rather with the process that links the resources to outcomes. The study identified four sets of networked community resilience resources: economic development, social capital, information and communication, and community competence. The economic capital indicator was further sub-divided into resource volume and diversity, resource equity and social vulnerability, and fairness of risk and vulnerability to hazards. In general, Norris does not propose economic resilience options for individual businesses and only superficially touch upon the economy as a whole. Equity of resource distribution and social vulnerability (including different exposures to hazards and risk mitigation) can critically influence how households cope with the aftermath of a disaster from a psychological/sociological point of view. They might, however, not necessarily have a great effect on businesses. On the other hand, the level and diversity of economic resources is a good proxy of macroeconomic resilience, as it is an indicator of single-sector dependence. A first translation of the Norris community resilience framework into an index was undertaken by Sherrieb et al. [28]. The authors confined their attention to economic development and social capital variables for lack of adequate specification and data for other features of the broader framework. The effort is commendable in two major ways. First, it narrowed the set of potential indicators through an examination of correlations between variables that indicated overlaps. Second, it attempted a validation of the index against historical data. Still this index is subject to the most of the criticisms of the various indicator studies reviewed above, such as the lack of a microeconomic theoretical foundation, absence of actionable economic variables, and reliance on an implicit equal weighting of indicators.

In an attempt to develop a composite index of community resilience to natural disasters and measuring disaster resilience, Burton [29] proposes a comprehensive set of variables that was validated against the recovery from Hurricane Katrina. The economic resilience index subcomponent builds upon the one of Cutter et al. [3] and unites proxies for the level of economic resources (percent population employed (including female labor), homeownership, income, sales volume of businesses), economic diversity (single-sector employment, business size, number of commercial establishments per 1000 population) and resource equity (number of doctors and lending institutions per 1000 population). The usefulness of most of these indicators for measuring economic resilience was already critically evaluated in this section for [3]. The remainder also shows little specific relation to the operation of businesses, which is not surprising as the economic resilience subcomponent was created to draw a picture of the economic vitality of communities rather than that of companies. The number of lending institutions per 1000 population directly relates to resource equity and, as such, affects the recovery potential of the community. It would, however, have little bearing on business recovery. The mean sales volume of businesses impacts economic and livelihood stability and is, as the author notes, a measure of a community's economic resources. It is, however, not a sufficient proxy for economic resilience. For instance, sales volume might not be affected by a disaster because it coincides with a low-sales quarter due to seasonal effects rather than being the result of resilience measures. The number of commercial establishments in an area can be a measure for sectoral diversity, which generally renders the economy less susceptible to disaster impact and hence more resilient.

We also summarize the work of Rose [11] in Table 3. Because this framework has been discussed in detail above, we simply repeat that the major strength of the approach is its grounding in production theory, which enables us to identify a core set of inherent and adaptive resilience options, several of which have been empirically documented as being able to significantly reduce disaster losses. At the same time, we acknowledge one of the major limitations of the framework so far—it is narrowly based on economic considerations alone, and would benefit from being expanded to include non-economic factors that have a bearing on short-run economic recovery.

The majority of the economic resilience indices discussed in the previous sections is of limited use for gauging the recovery of businesses after a disaster. Where indicators relevant for businesses or other organizations are included in the indices, they pertain to static or dynamic *micro*economic resilience. Implementation of these measures across a specific sector would increase business resilience at the mesoeconomic level. Only a few of the reviewed resilience indices address the macroeconomy.

5. Outline for a short-run economic resilience index

Our analysis indicates that few resilience frameworks and no actual indices adequately focus on business operations in the aftermath of a disaster. We contend that business behavior, in relation to static and dynamic resilience, is the key to economic recovery, at least in the short-run. Thus, all prior attempts at developing a resilience index, while applicable and useful for long-run analyses (more than a year after the event), are less likely to be useful for the short-run.

We now outline the development of a short-run economic resilience index, focusing on business behavior, that is intended to help gauge recovery potential in the short-run. It is based on the framework proposed in Rose [11]. The key issues are: (1) if and how to combine resilience actions at the micro, meso, and macro levels and (2) how to weight the various components.

The first challenge is whether a single index can best reflect the features of resilience at various levels of the economic aggregation hierarchy. We suggest it is best to separate the three levels first, and then explore ways to combine them. At the microeconomic level, i.e. the level of individual companies and organizations, a plethora of actionable measures to increase economic resilience exists. Following the reasoning in Section 3, business resilience consists of resilience options on both the customer and supplier side. While the former relates to coping with disaster impacts on the delivery of inputs and making effective use of resources, the latter pertains to ways to guarantee the delivery of outputs to customers. Some of these options relate to static economic resilience by aiming at diminishing losses (excess capacity, input or import substitution, etc.), while others facilitate speedy business recovery (reduce operating impediments, management, etc.) and hence belong to the dynamic resilience category.

At the mesoeconomic level, resilience options aim at bolstering the market or sectors and include, for instance, pricing mechanisms or information pooling. As discussed in Rose [11], market prices possess an "inherent resilience" as pricing enables goods and services to be redirected after a disaster to reflect highest value use. As another example, information clearing houses could be beneficial to help suppliers/customers in situations where, due to disaster, the usual customer/supplier base is (temporarily) lost or reduced.

At the macroeconomic level, resilience is very much influenced by interdependencies between sectors. Consequently, macroeconomic resilience is not only a function of resilience measures implemented by single businesses, but it is determined by the actions taken by all individual companies and markets including their interaction. Appropriate sample resilience performance measures at the macro-level would be, e.g., economic diversity to buffer impacts on individual sectors, or geographic proximity to economies not affected by disaster to facilitate access to goods or aid. We should note that we have analyzed the various levels of resilience but have not explored synergies or interactions very much beyond multiplier effects that translate major features of micro- and meso-level resilience into macroeconomic resilience.

The second consideration is how to evaluate the relative contribution of each resilience tactic (each measured as a single indicator) to overlap resilience. This issue of "weighting" has been finessed in nearly all prior cases. Several approaches for assigning weights to single indicators are discussed in the literature (e.g., [25]). For instance, weights can be derived empirically, e.g. using surveys, or, as a fall back, from a theoretical model of the indicator to be measured. An alternative way to assign weights is by consensus or relevance with respect to specific policy initiatives. We propose that the best way to develop weights is based on evidence of the relative effectiveness of each type of resilience tactic in actual practice. For example, if relocation has been found to have reduced losses five times more than conservation of scarce resources, then the former might be given a weight five times as great as the latter. Of course, one needs to be sure of causation, and this is not always easy given extenuating circumstances that arise in real world situations. Our economic framework does provide a structure, so that the identification of indicators will not just be a fishing expedition.

The weights would then have to be adjusted for differences in the context in which the index is to be applied, if it differs, and it likely will, from the original case. There is no one-size-fits-all approach to deriving weights, and the method of choice will depend on the particular problem at hand. It is best for each firm, household, government agency or emergency manager to derive or adapt weights, in addition to indicators according to local conditions. Policy needs to focus on the variables most likely to lead to successful recovery, and we have endeavored to present a framework and some guidelines for doing so.

Since resilience indices are relatively new and disasters infrequent, there has not yet been a case to test the contribution that this new construct can offer. But there are many examples of learning from experience in anticipation of future disasters, which would basically be embodied in disaster indices. For example, after suffering power outages from the Northridge Earthquake in 1994, many businesses and households in the Los Angeles area purchased portable electricity generators. These helped reduce losses significantly during the power outages caused by electricity deregulation gone awry in the early 2001–02. Sheffi [30] provides numerous examples of success stories of businesses that have been resilient in comparison to those that have not (e.g., mobile phone companies Nokia vs. Ericsson in response to a disruption of computer chip supplies in 2000). Actions that effectively reduce losses are a basis for indicator choice, and the compilation of an index helps bring this together, and, if weights are properly estimated, serve as basis for prioritizing options. Of course, not all firms learn from experience. Flynn [31] found that businesses founded after the Red River Floods of 1997 actually were much more likely to develop disaster recovery plans than were firms that had actually experienced the floods. However, a resilience index may make their options more vivid and spur more firms to plan ahead.

6. Conclusions

We have undertaken an evaluation of resilience indices from the perspective of their potential to measure and guide economic recovery in the aftermath of a disaster. We have focused on several component resilience indicators often placed in the “economics” category, broadly defined, in terms of their actual effects on recovery. Examples include literacy rates, unevenness of the income distribution, and percentage disabled. While all of these are worthy social goals, it is unlikely any of them would help any given *business* utilize its resources much more efficiently or recover more rapidly in the short-run. Of course, these three indicators, and others like them, do factor into overall economic development and the quality of life, and are definitely worthy of consideration for long-run *community resilience* indices.

At the same time, it is only fair to note that economics is only one part of the recovery from disasters. We are not suggesting economics in general, or the mainstream (neoclassical) approach used here, is the only thing that matters in recovery from disasters, even just economic recovery. In addition to the importance of non-economic factors, we also need to consider the existence of market failure, such as pollution, where the interests of business are not necessarily consistent with the interests of the community as a whole. In our context this is exemplified by the possibility that the dispersal of toxic waste or ordinary pollutants might be accelerated by more rapid recovery, partly because environmental concerns may be given lower priority. One approach is to go beyond ordinary market-based economic indicators, such as gross domestic product (GDP), and utilize broader measures of economic well-being. Fortunately, there has been a great deal of progress in these directions, even among economists (see, e.g., [32]).

A major reason to construct a resilience index is not only to study the recovery process, but also to improve it. This speaks to the importance of *actionable variables*. Several indicators included in resilience indices refer to background conditions and general trends that can hardly be improved in the near-term aftermath. Moreover, improvement of some of them is not necessarily consistent with other economic goals. For example, diversification of the economy may come at the cost of some economic activity. This refers to the age-old tradeoff between risk and return, where diversification is a risk reduction strategy. However, this is not to suggest diversification is not a worthwhile consideration, but just that one need consider its downsides. Beyond that, some of the other indicators need to be acknowledged as very much being immutable during the key period in which business take resilient actions. Examples would include literacy rates, percent disabled, and percent minority population. More research is needed to replace these indicators with ones that really matter to economic resilience and can be implemented in the short-run.

In order to identify more actionable resilience tactics and address the issue of weights, more empirical work is needed. Moreover, nearly all attempts to measure the effectiveness of resilience tactics have been in industrialized countries, so studies are needed for the different context found in developing countries.

Resilience measures adopted prior to a disaster may come at a cost, but they make recovery easier. Indicators can be very useful to gauge the capacity levels of various types of resilience and improvements in them over time. They can also be a useful first step in evaluating expenditures on resilience as part of overall risk management. The framework presented here provides the basis for cost-effective analysis across various types of resilience for comparison with other approaches to risk reduction, such as mitigation and insurance.

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